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**AUTOSPLIT TRUCK TRANSMISSION
CONCEPT PROTOTYPE**

TECHNICAL REPORT NO. 95005

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Corporate R&D-Detroit Center

EATON

Exhibit 21

**AUTOSPLIT TRUCK TRANSMISSION
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T. Genise

T. Genise

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ABSTRACT

The objective of this project is to design, fabricate, and develop a concept prototype transmission to demonstrate the AutoSplit concept. One AutoSplit concept prototype transmission was created and installed in a demonstration vehicle. The system uses a Super 10 base transmission, a modified Eaton ABS electronic control unit (ECU-2), a newly created driver display, and portions of software from the AutoShift and CEMT systems. The prototype was demonstrated to TCONA in September, 1994, and a product program was started shortly thereafter. This document describes the system as delivered to TCONA in September, 1994.

Presented are both brief and detailed definitions of the system, the driving procedure, and descriptions of the pertinent control algorithms. Plotted data of system parameters taken during actual vehicle shift testing is included to further explain system operation.

Figures include a system schematic, system and harness wiring diagrams, and shift schedule graphical presentations. A summary of patent coverage activity is included as well as selected listings of software.

It is concluded that the AutoSplit concept is very feasible as a product and offers a low cost, easy-to-drive automated transmission option to the trucking industry.

It is recommended that the concept be further developed towards a product, and that it be demonstrated to many fleet-owners, drivers, and customers to get important feedback. It is also recommended that the "intent-to-shift" feature be evaluated and considered for the product since it offers much value for virtually no additional cost.

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OBJECTIVE

The objective of this project is to design and build a concept prototype transmission to demonstrate the AutoSplit concept, based on the Super 10 transmission. The strategy used will be chosen to provide an operational prototype transmission in a vehicle for evaluation as soon as is feasible, and at the same time provide a prototype system utilizing the intended product hardware and software platforms.

CONCLUSIONS

The AutoSplit concept is very feasible and offers a low cost, simple, easy-to-drive automated transmission option to the trucking industry.

RECOMMENDATIONS

1. The AutoSplit concept should be further developed towards a product.
2. The AutoSplit concept prototype vehicle should be demonstrated to a diverse group of truck drivers, fleet managers, OEM's, and other customers to determine market interest and get important customer feedback.
3. The "intent-to-shift" feature should be integrated into the concept vehicle and be evaluated and considered for the product, since it offers much value for virtually no cost. This feature is simply a momentary button on the side of the shift knob — operated by the driver's thumb — that when depressed under conditions that a lever shift is allowed will initiate defueling of the engine and preselect the splitter to the next position, resulting in low lever-to-neutral forces and shifting with no throttle manipulation by the driver.

initiated and completed, but are assisted by the ECU in conjunction with engine control. It is the speed-sensing algorithms that allow detection of both neutral and new gear re-engagement that make this concept possible without expensive and complicated sensors. Sensing of neutral is not necessarily new, and was achieved during AutoSelect concept development. However, the method of sensing re-engagement of a gear in a lever-shifted transmission using only speed sensors is new and is essential to the success of this concept.

The driver display as pictured in Figure 1 has 5 lamps (LED's) that illuminate each of the 5 forward gear lever positions. When the vehicle is moving and the transmission is engaged in a gear, the lamp corresponding to that lever position is steadily lit (not flashing). Also, when in a gear and moving, the display flashes a lever position other than that one already lit if the system determines that shifting to that position is possible and allowable. When the driver initiates a lever shift and brings the shift lever to neutral, and the neutral sensing routine confirms neutral, the lamp that was indicating the engaged gear turns off and the flashing lamp that was indicating an allowable shift continues flashing for that "new" gear, indicating that the system is now directing the engine to a speed that would result in a synchronous condition for the new gear. If the vehicle speed changes enough while the transmission is in neutral for the system to change its selection for the "best" gear, the lamp corresponding to the lever position for that new gear will begin flashing and the system will command the engine to go to the speed to create synchronous for the new gear. When the driver engages the lever in a new gear position, and the system senses engagement of that new gear, and the lamp corresponding to that new lever position will be illuminated steadily.

The driver display also includes a push-button switch to select which splitter gear the system will engage at rest. Besides allowing the driver to start in either splitter ratio, this gives the system two reverse ratios. The prototype transmission, as delivered to TCONA, did not allow automatic or manual splitter shifting while moving in reverse. Reverse automatic or manual shifting is feasible and may be desirable, but would take additional software development.

Driving Procedure

To start from rest, the driver depresses the manual conventional clutch and engages the desired lever position, as in a manual transmission. If the selected splitter starting ratio is low (direct), and starting gears can be 1, 3, 5, etc. whereas if the selected splitter starting ratio is high, the starting gears will be one of 2, 4, 6, etc. To start the vehicle, the driver releases the clutch as in a manual gearbox vehicle.

When the ECU determines that it is time for an upshift (or downshift), and the shift is a **splitter-only shift**, the transmission automatically performs the shift just as an AutoShift transmission would. It should be noted that on splitter-only upshifts and downshifts the splitter clutch is engaged at a speed interval before synchronous (60 rpm). It was learned during FingerTipper, AutoSelect and AutoShift development that for automatic upshifts and downshifts, a smoother, cleaner engagement can be achieved by engaging the gear "before" synchronous is reached. This provides an amount of differential speed across the engaging clutch and gear to avoid "butting" for any length of time. Note that if the gear is engaged right at synchronous, a "butt" of the jaw (dog) clutch against the gear will occur and there will not be any differential speed to pull it off the butt. When this happens, the gearbox must go "past" synchronous to get off of the butt and engage. This makes for a longer and "clunky" shift since the backlash must be passed through again upon return of torque.

However, a **lever shift** is different and is driver-initiated. For a lever upshift, the driver releases the throttle, and pulls the transmission lever to neutral. The system senses neutral and then moves the splitter to its appropriate position. Also, the system commands the engine to go to the speed for synchronous for the next gear. The driver moves the lever to the next gear position. The system detects engagement and ramps the engine torque back up to what the driver is demanding.

During **lever shifts** when the engine is commanded to synchronous for the new gear, it is commanded to a speed that is a fixed amount "away" from synchronous for that gear. Note that if nearly exact synchronous speed was commanded, the gear engagement routine would

CONTROL ALGORITHM DESCRIPTION

Shift Schedule, Shift Types, and Shift Points

AutoSplit is unique from other automated mechanical transmissions in that its operation consists of both driver-initiated (lever) shifts and system-initiated, automatic (splitter) shifts. Therefore, a shift scheduling routine was created that recognizes the different types of shifts and takes different action for each. Figure 2 attempts to summarize this shift schedule.

In Figure 2, the automatic splitter shift points are throttle-modulated just as in AutoShift. That is, the greater the throttle opening, the higher the shift point. In Figure 2, these shifts are the 1-2, 2-1 shifts, the 3-4, 4-3 shifts, and so on. The allowable shift speeds for each gear are noted by the arrows. For example, for the 1-2 shift, the arrows pointing down at the upper end of the first gear "speed line" from 1500 rpm to 1800 rpm signify that 1-2 upshifts are initiated from 1500 to 1800 rpm input speed depending upon throttle. Note that the arrows point down to indicate that the input speed must come down to complete the 1-2 shift.

The lever shifts on Figure 2 indicate different information than the splitter shifts do. The lever shifts are the 2-3, 3-2 shifts, the 4-5, 5-4 shifts, and so on. Note that these are called "shift areas." This means that this is the allowable area for those shifts by the system. It is up to the driver to determine the input speed at which those shifts are actually initiated. Simply interpreted, if the transmission is in 2nd gear (4th gear, 6th gear, etc), the input speed is above 1375 rpm, and neutral is sensed, the system recognizes it as a 2-3 lever shift. Once neutral is seen, the splitter is shifted to the low position and the engine is commanded to a speed that achieves synchronous for the new gear, which is 3rd.

Figure 3 attempts to illustrate this shift logic in a different manner. Note the "notch" in the splitter upshift line above 90 percent driver demand (percent throttle). This is software simulating a "ride-through-detent" feature at wide-open-throttle. Each of the "curves" in Figure 3 only apply when the transmission is in the appropriate gear for that line. For example, the "lever upshifts" line only applies when the transmission is in gear 2, 4, 6, or 8.

AutoSplit Shift Schedule

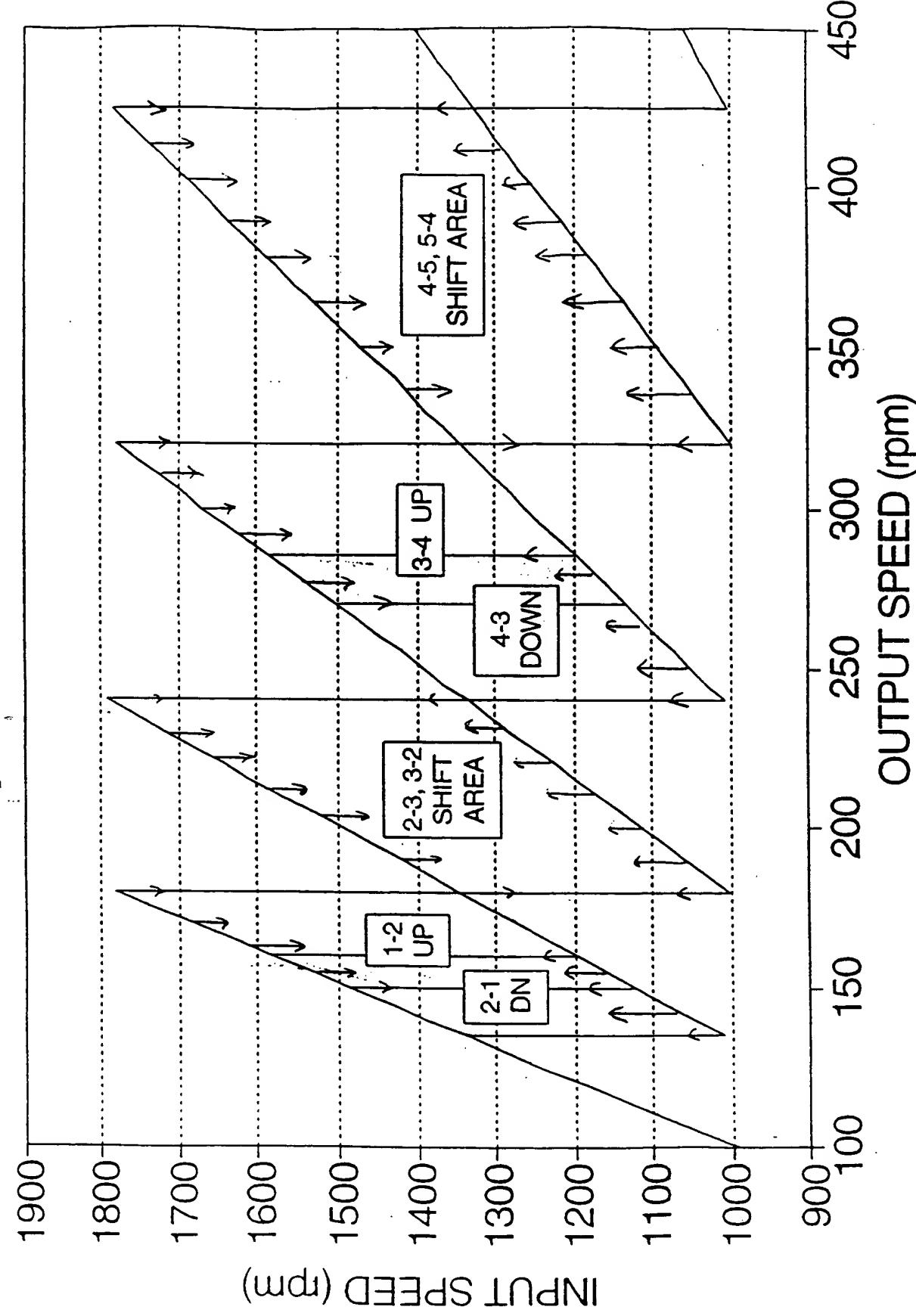


Figure 2

Zero Driveline Torque

Zero driveline torque is the gross engine torque needed to create zero torque in the driveline (at the flywheel). Gross engine torque is the total torque being produced by the engine, including engine friction and internal engine accessories (i.e. water pump, etc.). A gross engine torque of zero corresponds to a zero fueling condition. The gross engine torque needed to produce zero driveline torque is a simple calculation and assumes fixed OEM-installed accessory torque. Also, it doesn't take into account the torque to accelerate the engine. Note that zero gross engine torque is not the same as zero driveline torque. It generally takes some positive gross engine torque to create zero driveline torque. The software variable for zero driveline torque is:

```
needed_percent_for_zero_flywheel_trq =  
    percent_torque_accessories + nominal_friction_percent_trq
```

In J1939 and AutoSplit software, all torque values are expressed as a percent of the available gross engine torque (peak torque). Therefore, this variable above — "needed_percent_for_zero_flywheel_trq" — is the amount of gross engine torque that must be requested via J1939 to achieve zero driveline torque. One use of this variable in AutoSplit is in helping the driver move the lever to neutral while the clutch is engaged. Whenever the accelerator pedal is released, zero driveline torque is commanded for 400 msec. Whenever the accelerator pedal is reapplied, zero driveline torque is commanded for 250 msec. These "zero driveline torque" intervals are nearly imperceptible to the driver. Note that with AutoSplit, the splitter cannot be preloaded, or preselected, toward the next gear as in the Super 10 transmission. In the stock Super 10 transmission, the splitter is preloaded towards the next gear before the lever is brought to neutral. This allows the splitter to come out-of-gear before the driver moves the lever to neutral. This makes the lever force to neutral very low in the Super 10. However, a simple enhancement to AutoSplit called the "intent-to-shift" feature (see Recommended Future Actions section) will allow this splitter preselection feature as well as many other advantages and should be evaluated by the AutoSplit team.

is preloaded to overdrive as both of the solenoids are turned on. Gross engine torque follows the desired torque quite well, both in "predip" and in "recovery".

Figure 4 also shows that the solenoids are commanded both on to shift the splitter into overdrive before synchronous is reached (input speed has not yet reached GOS). This is to achieve smoother shifts and to avoid "butting". Please see the fourth paragraph in the "Driving Procedure" section of this report for further explanation of this.

On Figure 4, the "splitter position" trace comes from a linear potentiometer attached to the splitter shift rail. It is not part of the AutoSplit system, but was installed for development purposes. Note that during the portions of time where the splitter rail moves the fastest (into neutral, and then into gear), the signal "drops out" or goes abnormally low. This is an unexplained phenomenon in either the potentiometer or its signal conditioning system, and was not addressed, since the potentiometer system is "good enough" for the development needs.

Figure 5 shows the same shift as in Figure 4, but with some different signals plotted. "Desired engine speed" is the speed that the system is requesting the engine to go to. In this case, a speed of 65 rpm below synchronous (GOS is synchronous) is requested. The two variables "gear pointer" and "current gear" indicate what gear ratio is being sensed and what gear ratio has been confirmed, respectively. In other words, whenever the gear sensing software routine "senses" that the transmission is in a gear (by looking at the ratio of input speed to output speed), the gear pointer is assigned the number of that gear (i.e., "5" for 5th gear). If no gear ratio is sensed, gear pointer is zero. Current gear cannot change in value until gear pointer has changed consistently for a certain amount of time. For the shift in Figure 5, current gear changes from 5 to zero only after gear pointer is consistently zero for 80 milliseconds(ms). Similarly, current gear does not change to 6 (indicating that 6th gear has been engaged) until gear pointer is consistently 6 for 100 ms. This "in-gear" timer is increased to 300 ms (or more) for lever shifts.

on this trace, a desired torque request to the engine of a value to result in zero driveline torque initiated this bump. If Figure 8 were of a power downshift - one which there was significant positive torque in the driveline before the shift - the predip phase would have started with a ramping down of gross engine torque. See the "Zero Driveline Torque" section for more explanation.

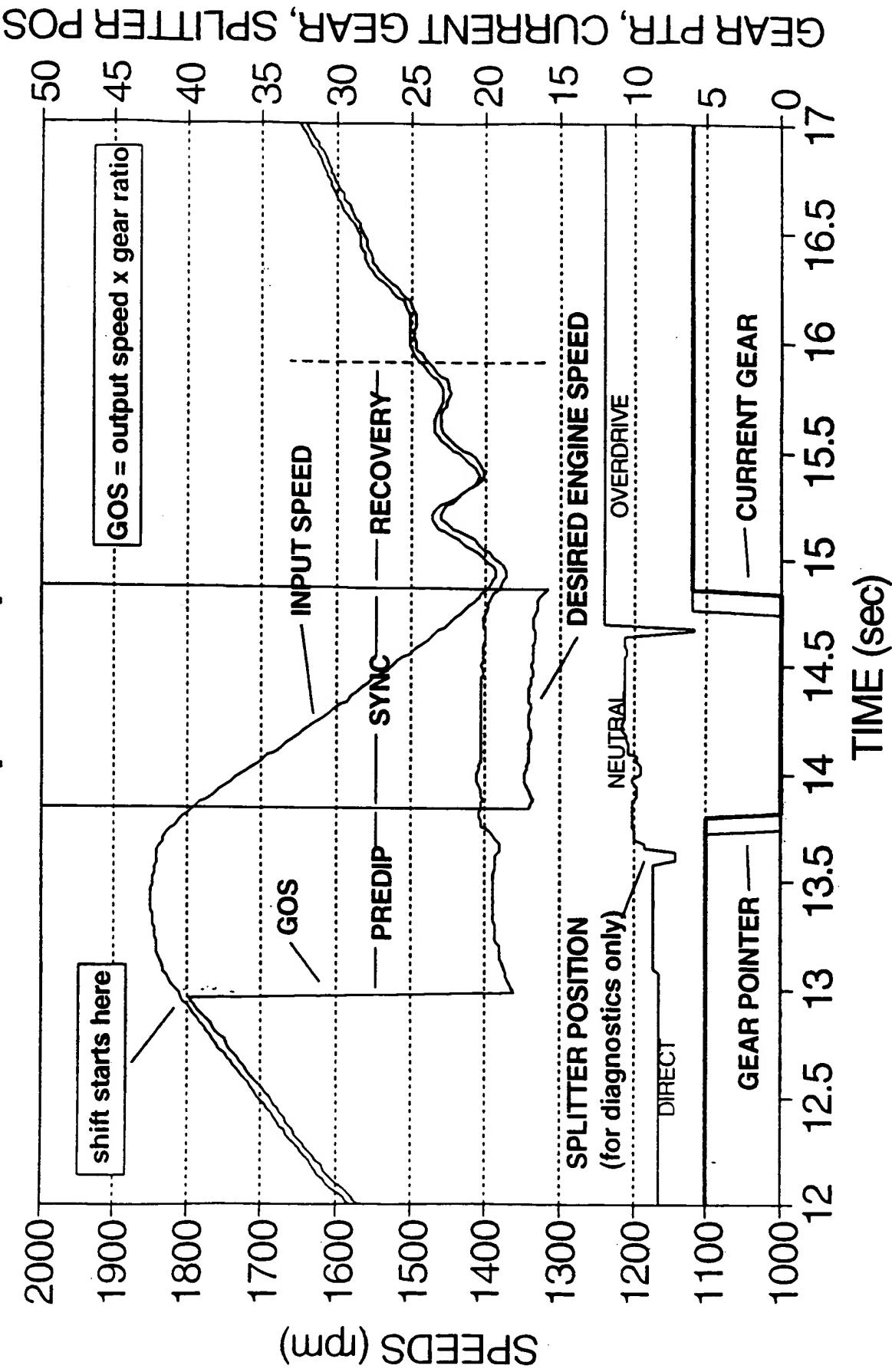
Figure 8 introduces a new variable - "trans sync error" - which is the speed error across the splitter clutch to be engaged. This variable is offset for plotting purposes by adding 120 to each value so that it could fit on the plot. Therefore, when trans sync error is at 120, the speed error across the splitter clutch is zero. When the trans sync error becomes greater than + or - 30 rpm (between 150 and 90 on Figure 8) at the transmission input, the value is set to 4000 (for software development purposes). This variable, trans sync error, is used by the gear sensing routine to indicate that a gear ratio is sensed. In other words, when trans sync error is between + or - 30 rpm for a given ratio, gear pointer takes on a value of that gear number. Note on Figure 8 how trans sync error takes on a value between 30 and -30 rpm for a very short period of time while the input speed "passes through" a speed range resulting in synchronous for the previous gear, which is 5th.

Figure 9 displays the same shift data as in Figure 8, but with different variables plotted. Note that the desired engine speed is set to 65 rpm above GOS until the input speed is approaching GOS. It then switches to 65 rpm below GOS. This setting of desired engine speed first to 65 above is to ensure that the engine fuels in such a manner that input speed reaches GOS as quickly as possible. However, the desired engine speed must be switched down to below GOS during engagement - otherwise the engine would go to full torque for the period of time that it takes to confirm gear engagement as it tries to maintain the 65 rpm speed difference.

Figure 10 is of a 7-6 lever downshift with a range downshift, also. As in Figure 6, this shift displays a delayed engagement of the shift lever after synchronous is reached.

AutoSplit Shift Data

5-6 Automatic Splitter Upshift



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Figure 5

AutoSplit Shift Data

6-7 Lever & Range Upshift - Fast Engage

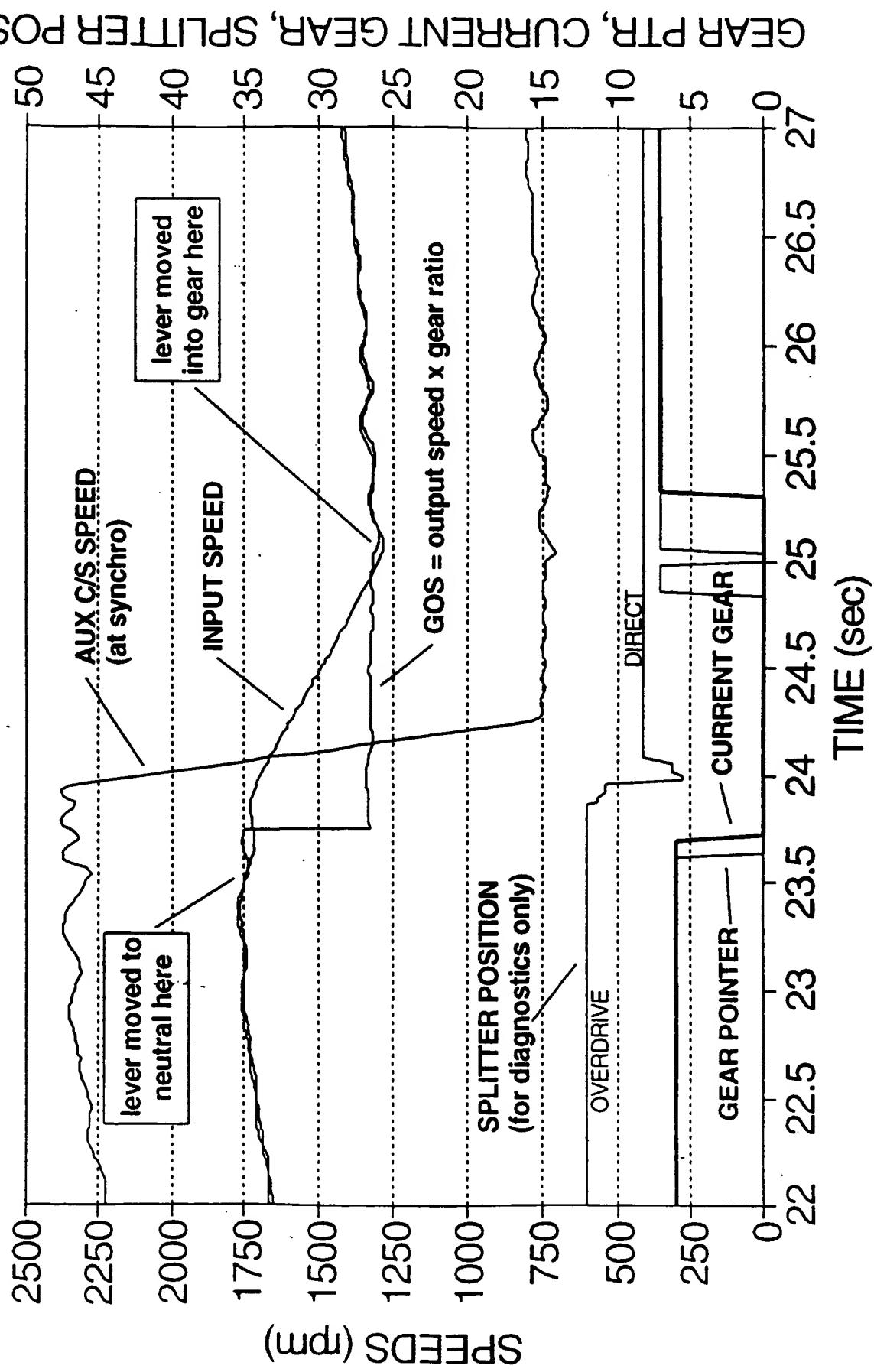
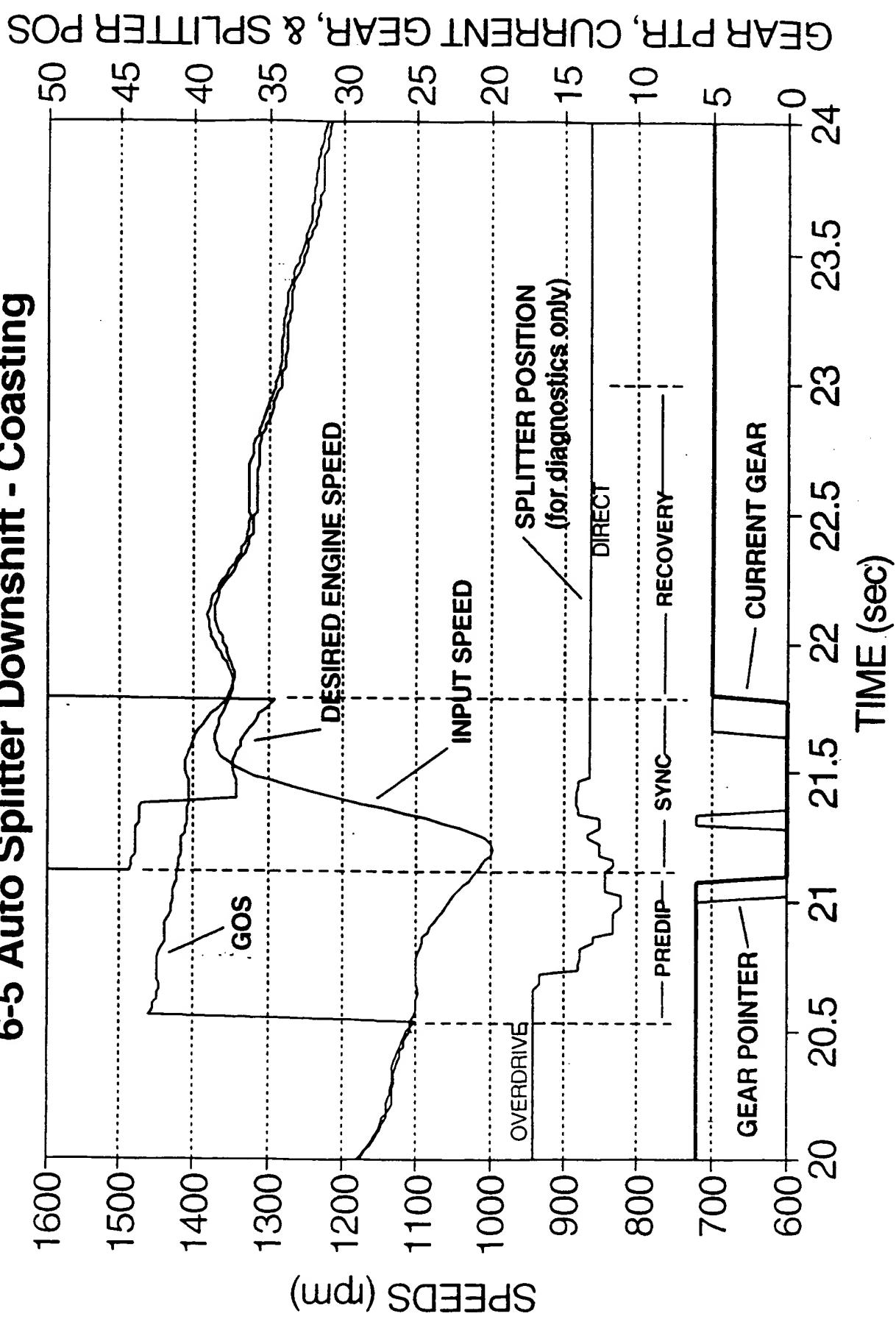


Figure 7

AutoSplit Shift Data

6-5 Auto Splitter Downshift - Coasting



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Figure 9

Unexpected Driver Actions

This section actually documents two operation problems observed during AutoSplit development and the action taken to correct the conditions. Since a driver is part of the control system, these observations were made when the development entered the phase that explores what happens when the driver does something abnormal. Studying these cases may help the reader to better understand the AutoSplit system.

Observed Problem No. 1: The transmission is in 5th gear and the input speed is close to the shift point. The driver moves the lever to the 7/8 position thinking he is making a 6-7 shift. It grinds and doesn't engage because the system is synchronizing for 6th gear. He looks at the driver display, realizes his mistake, and moves the lever back to the 5/6 position and then has no throttle response.

Cause: The "sync" mode is holding the engine speed at 65 rpm below synchronous for 6th gear. Either the range is slipping or the splitter is grinding, so the system thinks the lever is in neutral and holds the input speed at 65 rpm below synchronous indefinitely. The system senses neutral across the whole transmission using input speed and output speed and cannot discern what is causing neutral.

Solution: Every two seconds while in sync mode, the engine is commanded to momentarily pass through synchronous speed and then back to 65 rpm below. Confirmation of gear engagement is suppressed during this time. This will "unblock" the range and/or the splitter.

Additional Benefit: Every once and a while, the AutoSplit system misses a splitter shift for some unknown reason. Note that there is a driver in the control "loop" and this introduces unknowns. When this happens, the splitter just ratchets at 65 rpm below synchronous. The same condition can happen to the range where it does not become unblocked. The above resolves this condition in two seconds or less.

PDS No. 94-rTRN-387 - Implementation of Zero Flywheel Torque Algorithms in Automated Mechanical Transmissions

This disclosure describes the "zero torque" algorithms exploited in AutoSplit, but applicable to many other automated products. It is essentially a continuation and expansion of 93-rTRN-466 of which an application was applied for.

PDS No. 94-rTRN-396 - Intent-to-Shift Switch Addition to the Eaton AutoSplit-Type Transmission

This disclosure describes a feature that is not currently on the AutoSplit prototype. However, it is a slight change to the hardware and adds much value to the product. It is highly recommended that this feature be evaluated soon.

AutoSplit Concept Vehicle Wiring Diagram

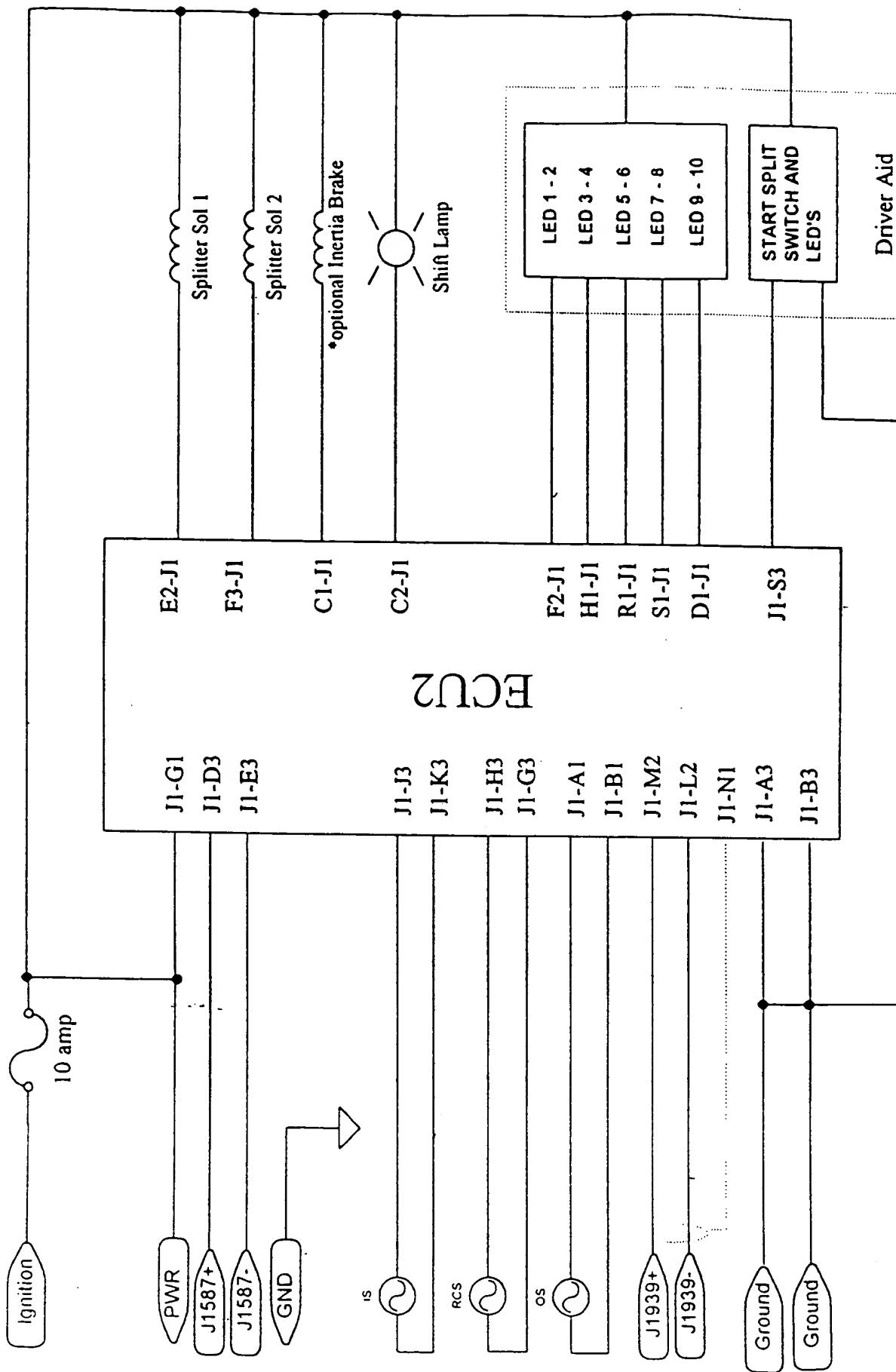


Figure 11

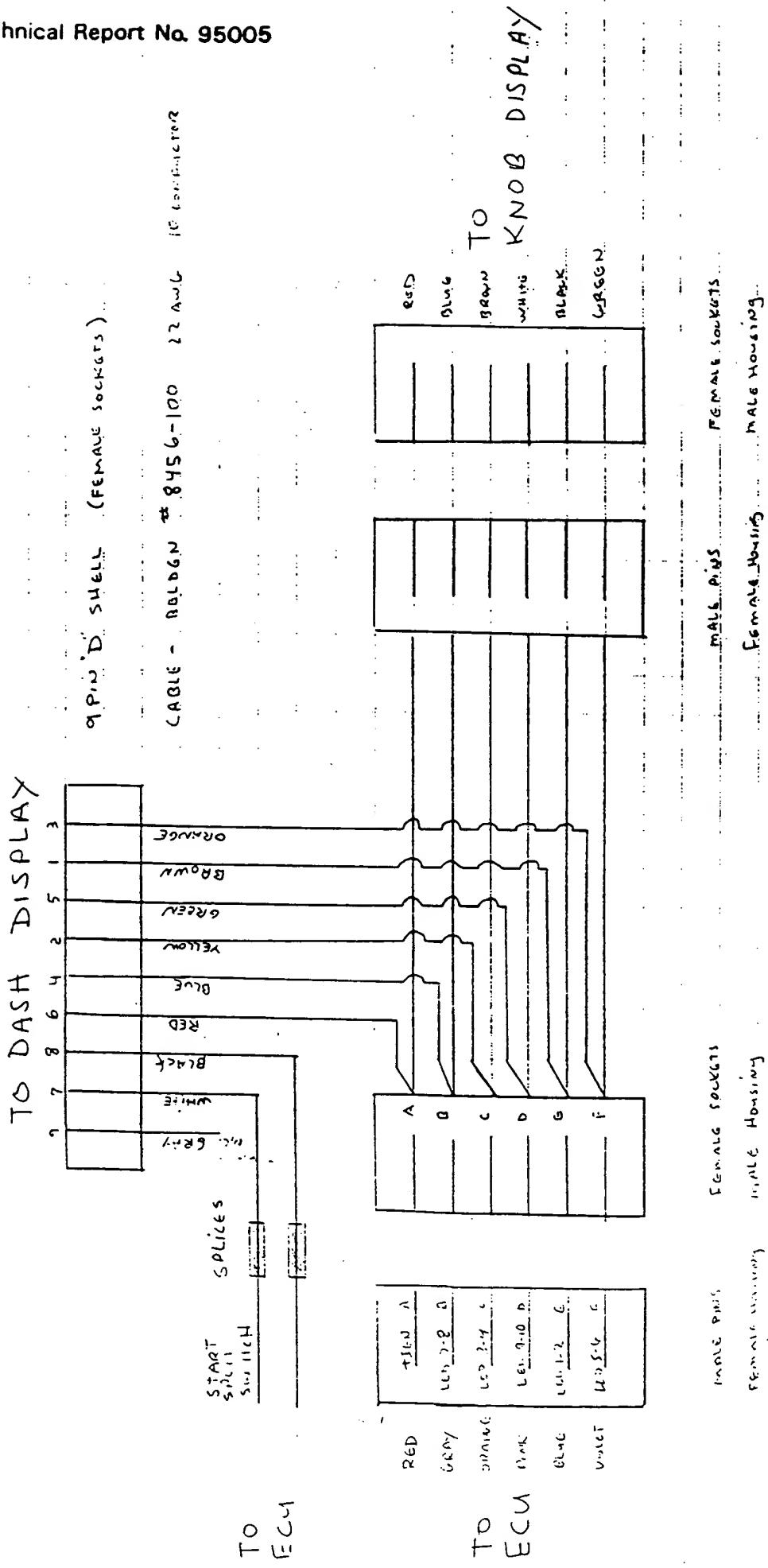


Figure 13

AUTOSPLIT SOFTWARE

The AutoSplit Concept prototype and software, as delivered to TCONA in September, 1994, can be viewed and copied from a CoRD-DC VAX directory. It is:

ERCENG:::[GENISE.ASPLIT]

This directory contains the complete AutoSplit software code archived by the "PKZIP" utility. Also, it contains a readable listing of the four major software modules that contain the system control routines for AutoSplit. These files are:

- ASPLIT.ZIP - complete archived code
- DRL_CMDS.C96 - engine control logic
- SEL_GEAR.C96 - gear selection logic
- SEQ_SHFT.C96 - shift sequencing logic
- TRNS_ACT.C96 - solenoid control logic

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